4.3.8 Geological Hazards

The following section provides the hazard profile (hazard description, location, extent, previous occurrences and losses, probability of future occurrences, and impact of climate change) and vulnerability assessment for the geological hazards in Gloucester County.

2022 HMP Update Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2015 and 2021.
- Updated New Jersey Geological Survey and Water landslide susceptibility data (2016) was utilized for the risk assessment.

4.3.8.1Profile

Hazard Description

Geologic hazards are any geological or hydrological processes that pose a threat to humans and natural properties. Every year, severe natural events destroy infrastructure and cause injuries and deaths. Geologic hazards may include volcanic eruptions and other geothermal related features, earthquakes, landslides and other slope failures, mudflows, sinkhole collapses, snow avalanches, flooding, glacial surges and outburst floods, tsunamis, and shoreline movements. For the purpose of this HMP update, only landslides and land subsidence/sinkholes will be discussed.

Areas underlain by carbonate rock may contain surface depressions and open drainage passages making such areas unstable and susceptible to subsidence and surface collapse. As a result, the alteration of drainage patterns, placement of impervious coverage, grade changes or increased loads can result in land subsidence and sinkhole formation (New Jersey Office of Emergency Management 2019).

While fewer karst features have been mapped in existing urban areas, human activity can often be the cause of a subsidence or sinkhole event. Furthermore, the lack of karst features exhibited in maps of urban areas is likely a result of development activities that disguise, cover, or fill existing features rather than an absence of the features themselves. Leaking water pipes or structures that convey stormwater runoff may also result in areas of subsidence as the water dissolves substantial amounts of rock over time. In some cases, construction, land grading, or earthmoving activities that cause changes in stormwater flow can trigger sinkhole events. Subsidence or sinkhole events may occur in the presence of mining activity, especially in areas where the cover of a mine is thin, even in areas where bedrock is not necessarily conducive to their formation. The US Department of Interior indicated that sinkhole development normally occurs where the interval to the ground surface is less than three to five times the thickness of the extracted seam, and the maximum interval is up to ten times the thickness of the extracted seam (J. F. Abel 1980). Sub-surface (i.e. underground) extraction of materials such as oil, gas, coal, metal ores (copper, iron, and zinc), clay, shale, limestone, or water may result in slow-moving or abrupt shifts in the ground surface.

Landslides

According to the U.S. Geological Survey (USGS), the term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over steepened slope is the primary reason for a landslide, there are other contributing factors (USGS 2013). Among the contributing factors are: (1) erosion by rivers, glaciers, or ocean waves which create over-steepened slopes; (2) rock and soil slopes weakened through saturation by snowmelt or heavy rains; (3) earthquakes which create stresses making weak slopes fail; and (4) excess weight from rain/snow accumulation, rock/ore stockpiling, waste piles, or man-made structures. Scientists from the USGS also monitor stream flow, noting changes in sediment load in rivers and streams that may result from landslides. All of these types of landslides are considered aggregately in USGS landslide mapping.

In New Jersey, there are four main types of landslides: slumps, debris flows, rockfalls, and rockslides. Slumps are coherent masses that move downslope by rotational slip on surfaces that underlie and penetrate the landslide deposit (Briggs E 2009). A debris flow, also known as a mudslide, is a form of rapid mass movement in which loose soil, rock, organic matter, air, and water mobilize as slurry that flows downslope. Debris flows are often caused by intense surface water from heavy precipitation or rapid snow melt. This precipitation loosens surface matter, thus triggering the slide. Rockfalls are common on roadway cuts and steep cliffs. These landslides are abrupt movements of geological material such as rocks and boulders. Rockfalls happen when these materials become detached. Rockslides are the movement of newly detached segments of bedrock sliding on bedrock, joint, or fault surfaces (Delano 2009).

Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors that include:

- Erosion by rivers, glaciers, or ocean waves create over-steepened slopes
- Rock and soil slopes are weakened through saturation by snowmelt or heavy rains
- Earthquakes create stresses that make weak slopes fail
- Earthquakes of magnitude 4.0 and greater have been known to trigger landslides
- Volcanic eruptions produce loose ash deposits, heavy rain, and debris flows
- Excess weight from accumulation of rain or snow or stockpiling of rock or ore, from waste piles or man-made structures may stress weak slopes to fail (USGS 2021)

Landslides may be triggered by both natural and human-caused changes in the environment. Warning signs for landslide activity include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavement, or sidewalk

- Soil moving away from foundations
- Ancillary structures, such as decks and patios, tilting and moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity
- Sudden increase in creek water levels while rain is still falling or just recently ended
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together (USGS, Landslide Preparedness 2021)

Subsidence/Sinkholes

Land subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials (USGS 2000). Subsidence often occurs through the loss of subsurface support in karst terrain, which may result from a number of natural- and human-caused occurrences. Karst describes a distinctive topography that indicates dissolution of underlying carbonate rocks (limestone and dolomite) by surface water or groundwater over time. The dissolution process causes surface depressions and the development of sinkholes, sinking stream, enlarged bedrock fractures, caves, and underground streams (New Jersey Office of Emergency Management 2019).

Sinkholes, the type of subsidence most frequently seen in the New Jersey, though more clustered in the northern part of the state, are a natural and common geologic feature in areas with underlying limestone, carbonate rock, salt beds, or other rocks that are soluble in water (The New Jersey Cooperator 2015). Over periods of time, measured in thousands of years, the carbonate bedrock can be dissolved through acidic rain water moving in fractures or cracks in the bedrock. This creates larger openings in the rock through which water and overlying soil materials will travel. Over time the voids will enlarge until the roof over the void is unable to support the land above will collapse forming a sinkhole. In this example the sinkhole occurs naturally, but in other cases the root causes of a sinkhole are anthropogenic. These anthropogenic causes can include those that involve changes to the water balance of an area such as: over-withdrawal of groundwater; diverting surface water from a large area and concentrating it in a single point; artificially creating ponds of surface water; and drilling new water wells. These actions can serve to accelerate the natural processes of creation of soil voids, which can have a direct impact on sinkhole creation (NJOEM 2019).

Both natural and man-made sinkholes can occur without warning. Slumping or falling fence posts, trees, or foundations, sudden formation of small ponds, wilting vegetation, discolored well water, and/or structural cracks in walls and floors, are all specific signs that a sinkhole is forming. Sinkholes can range in form from steep-walled holes, to bowl, or cone-shaped depressions. When sinkholes occur in developed areas they can cause severe property damage, disruption of utilities, damage to roadways, injury, and loss of life (NJOEM 2019).

Location

In general, while predicting where geologically vulnerable areas is difficult, there are specific areas in the County that have previously experienced these events or have been predicted to have increased vulnerability due to land use change, topographical manipulation, and other human-caused land modifications.

The County is largely composed of low-lying rivers and coastal plains. High elevation in the county is found in the area along Route 654 southeast of Cross Keys that reaches approximately 180 feet (55 m) above sea level; the lowest point is at sea level on the Delaware River. The area most susceptible to landslides is concentrated along the western border of Gloucester County (Peak Bagger 2020).

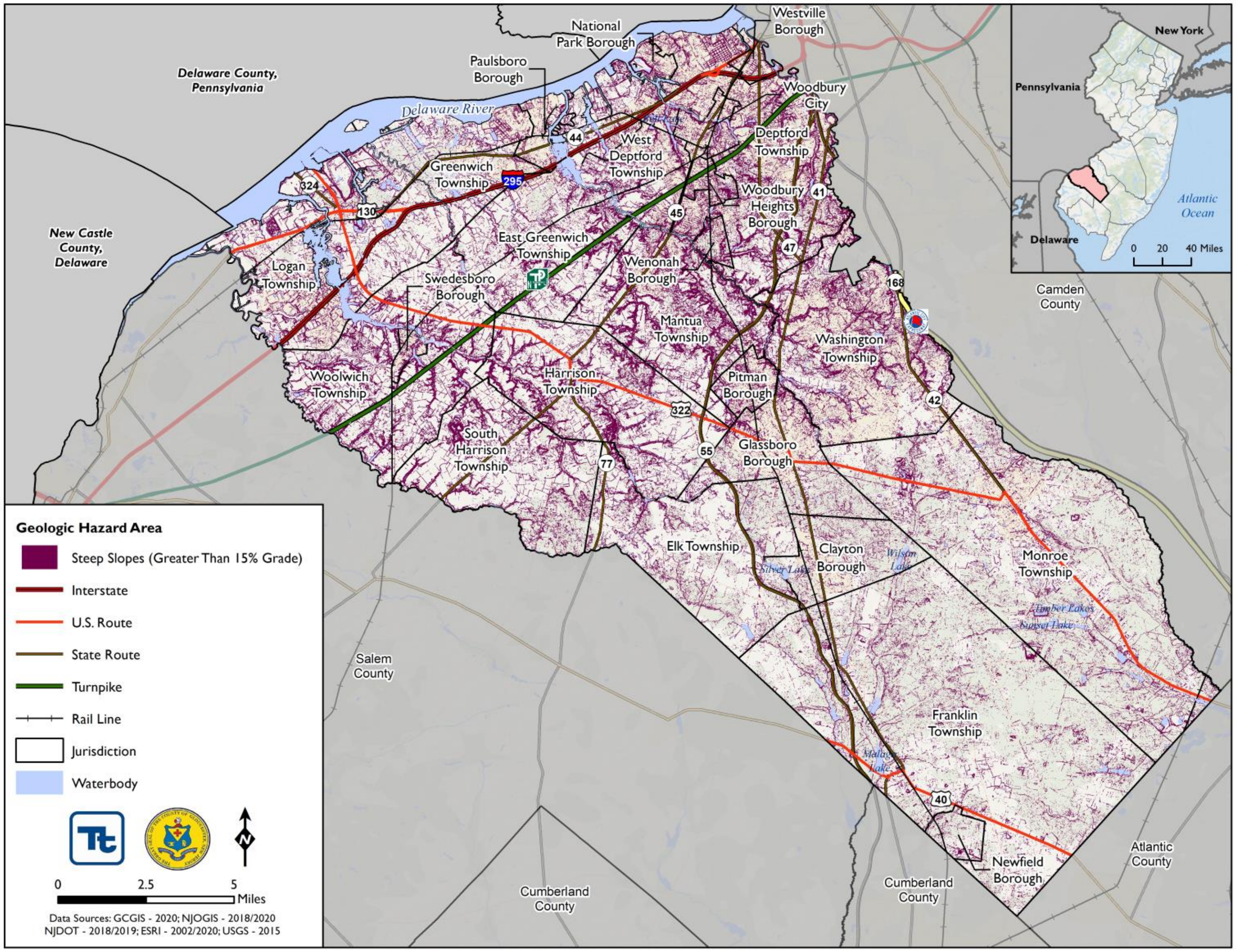
Landslides

Landslides are common in New Jersey, primarily in the northern region of the State. The New Jersey Geologic Survey (currently known as the New Jersey Geological and Water Survey) determined landslide susceptibility is highest in the northern counties. Areas within the northern region are classified into Class A, B, and C landslide susceptible classes, and several subclasses within the main classifications. These classes are consistent with HAZUS User Manual Table 9.2. Class A areas in New Jersey include classes AII, AIV, AVI which is strongly cemented rock at varying slope angles; Class B includes classes BIII, BIV, BV, and BVI which includes weakly cemented rock and soil at varying slope angles; and Class C includes classes CV, CVI, CVII, CIX, and CX which includes shale and clayey soil at varying slope angles.

According to the New Jersey Department of Water Supply and Geoscience, as of 2021, there have been no recorded incidents of landslides within Gloucester County. The closest incident was in northwest Camden County along the Delaware River and was reported to be related to debris flow. However, just because there have been no recorded landslide events, does not mean that the area is safe from any future occurrences. The figure below shows the areas of steep slope that are susceptible to landslide in Gloucester County.

This region is within the Cretaceous Geologic Age zone which is composed of sand, silt and clay which contribute to the susceptibility of landslides in communities along the river. The County has 42.7 square miles of land areas within the moderate susceptibility/low incidence class, which is one of the highest in New Jersey.

Figure 4.3.8-1. Areas of Steep Slopes (Greater Than 15% Grade) that are Susceptible to Landslides in Gloucester County



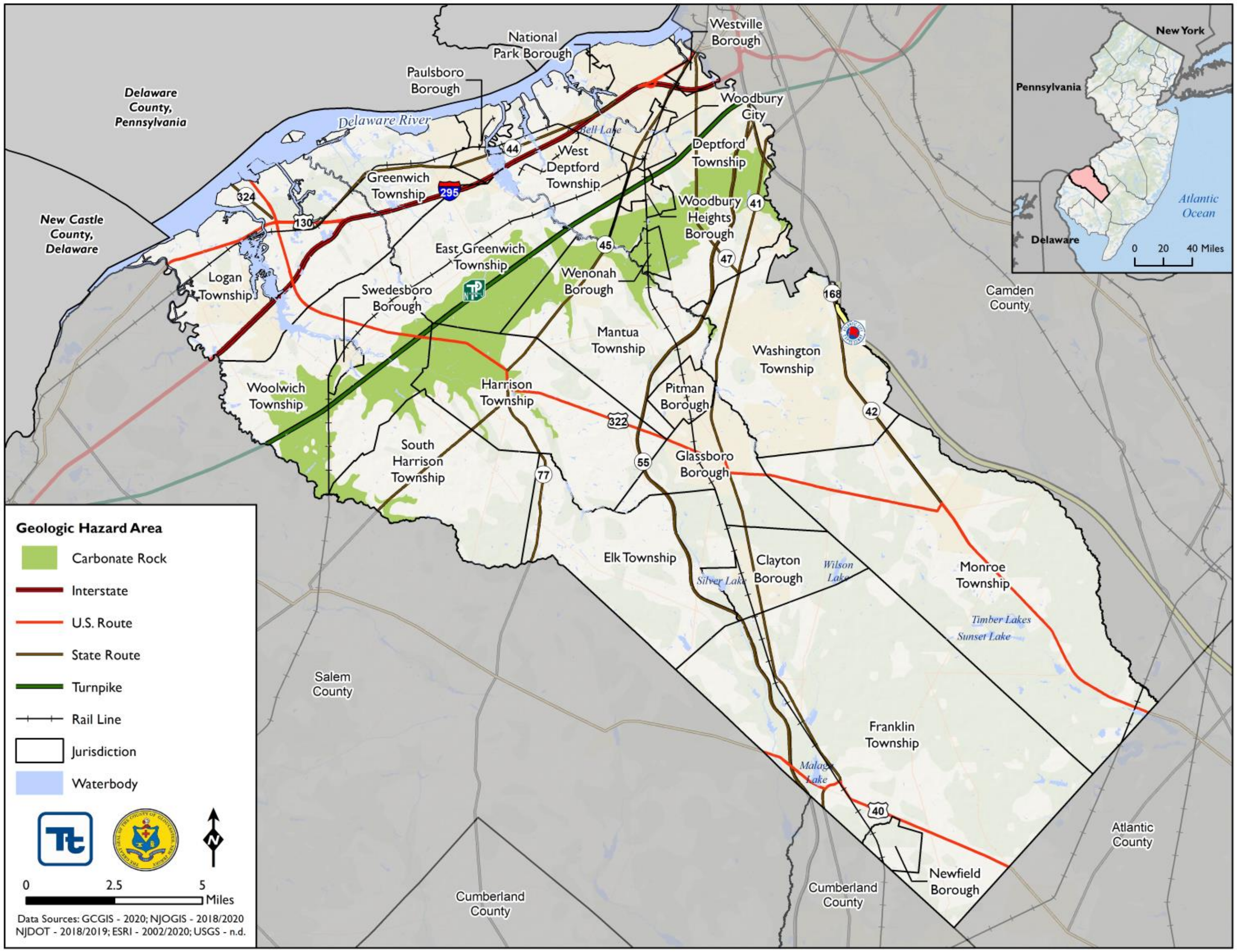
Subsidence/Sinkholes

New Jersey is susceptible to the effects of subsidence and sinkholes, primarily in the northern region of the State. The State's susceptibility to subsidence is due in part to the number of abandoned mines throughout New Jersey. The State historically was an iron-producing state and the first mines in New Jersey were drilled in the early 1700s, with operations continuing until 1986 when the last active mine was closed. Although mines have closed in New Jersey, continued development in the northern part of the State has been problematic because of the extensive mining there which has caused widespread subsidence. One problem is that the mapped locations of some of the abandoned mines are not accurate. Another issue is that many of the surface openings were improperly filled in, and roads and structures have been built adjacent to or on top of these former mine sites.

Naturally occurring subsidence and sinkholes in New Jersey occur within bands of carbonate bedrock. In northern New Jersey, there are more than 225 square miles that are underlain by limestone, dolomite, and marble which make the region more susceptible to subsidence, compared to the south. However, it is worth noting that there are regions within Gloucester County that are susceptible to land subsidence due to presence of carbonate rock.

Figure 4.3.8-2 illustrates the locations of carbonate-bearing geologic formations of New Jersey. These formations are areas of potential natural subsidence. These geologic units contain a high enough percentage of carbonate minerals such as calcite and/or dolomite for karst features such as sinkholes to form. Some of these units are more prone to sinkhole development than others due to a greater carbonate content in the rock. Although not every unit listed has documented sinkholes, all are susceptible to dissolution by groundwater so various karst features, including sinkholes, may be found on any of these units.

Figure 4.3.8-2. Carbonate Rock Locations in Gloucester County



Extent

Landslide

To determine the extent of a landslide hazard, the affected areas need to be identified and the probability of the landslide occurring within some time period needs to be assessed. Natural variables that contribute to the overall extent of potential landslide activity in any particular area include soil properties, topographic position and slope, and historical incidence. Predicting a landslide is difficult, even under ideal conditions and with reliable information. As a result, the landslide hazard is often represented by landslide incidence and/or susceptibility, as defined below:

- Landslide incidence is the number of landslides that have occurred in a given geographic area. High incidence means greater than 15 percent of a given area has been involved in landsliding; medium incidence means that 1.5 to 15 percent of an area has been involved; and low incidence means that less than 1.5 percent of an area has been involved (Geological Hazards Program Date Unknown).
- Landslide susceptibility is defined as the probable degree of response of geologic formations to natural or artificial cutting, to loading of slopes, or to unusually high precipitation. It can be assumed that unusually high precipitation or changes in existing conditions can initiate landslide movement in areas where rocks and soils have experienced numerous landslides in the past. Landslide susceptibility depends on slope angle and the geologic material underlying the slope. Landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. High, medium, and low susceptibility are delimited by the same percentages used for classifying the incidence of landsliding Subsidence/Sinkhole (New Jersey Office of Emergency Management 2019).

Subsidence/Sinkholes

Subsidence and sinkholes occur slowly and continuously over time or abruptly for various reasons. Subsidence and sinkholes can occur due to either natural processes (karst sinkholes in areas underlain by soluble bedrock) or as a result of human activities. Subsidence in the U.S. has directly affected more than 17,000 square miles in 45 states, and associated annual costs are estimated to be approximately $125 million. The principal causes of subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost (USGS, Measuring Land Subsidence from Space 2000) There are several methods used to measure land subsidence. Global Positioning System (GPS) is a method used to monitor subsidence on a regional scale. Benchmarks (geodetic stations) are commonly space around four miles apart (California Department of Water Resources 2015)

Another method which is becoming increasingly popular is Interferometric Synthetic Aperture Radar (InSAR). InSAR is a remote sensing technique that uses radar signals to interpolate land surface elevation changes. It is a cost-effective solution for measuring land surface deformation for a region while offering a high degree of spatial detail and resolution (State of California 2014).

Previous Occurrences and Losses

Various sources provide historical information regarding previous occurrences and losses associated with geologic hazards throughout the State of New Jersey and Gloucester County; therefore, the loss and impact information for many events varies depending on the source. The accuracy of monetary figures discussed is based only on the available information in cited sources.

FEMA Major Disasters and Emergency Declarations

Between 1954 and 2020, FEMA issued a disaster (DR) or emergency (EM) declaration for the State of New Jersey for one geological hazard-related event, classified as a mudslide. Of those events, Gloucester County has not been included any declarations (EM and DR) (FEMA 2021).

U.S. Department of Agriculture Disaster Declarations

The USDA Secretary of Agriculture is authorized to designate counties as disaster areas to make emergency loans to producers suffering losses in those counties and in counties that are contiguous to a designated county. Gloucester County was not included in declarations related to geologic hazards from 2015 to 2021 (USDA 2021)

Previous Events

There are no reported geological hazard events in Gloucester County. There has only been one documented geological event that occurred in the region, specifically in Camden County (New Jersey Office of Emergency Management 2019).

Probability of Future Occurrences

Based upon risk factors for and past occurrences, it is unlikely, yet possible that geological hazards will occur in Gloucester County in the future. It is estimated that Gloucester County might see an increase in geological related events in the future, with increasing intense weather events, erosion, and decrepit and abandoned underground infrastructure.

In Section 4.1, the identified hazards of concern for Gloucester County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Committee, the probability of occurrence for geological hazards in the County is considered ‘unlikely’ (not likely to occur or less than 1 percent annual chance of occurring).

Climate Change Impacts

Providing projections of future climate change for a specific region is challenging. Shorter term projections are more closely tied to existing trends making longer term projections even more challenging. The further out a prediction reaches the more subject to changing dynamics it becomes.

Climate change includes major changes in temperature, precipitation, or wind patterns, which occur over several decades or longer. Due to the increase in greenhouse gas concentrations since the end of the 1890s, New Jersey has experienced a 3.5° F (1.9° C) increase in the State's average temperature (Office of the New Jersey State Climatologist 2020) which is faster than the rest of the Northeast region (2° F [1.1° C]) (Melillo, Climate change impacts in the United States 2014) and the world (1.5° F [0.8° C]) (IPCC 2016). This warming trend is expected to continue. By 2050, temperatures in New Jersey are expected to increase by 4.1 to 5.7° F (2.3° C to 3.2° C) (R. D. Horton 2015). Thus, New Jersey can expect to experience an average annual temperature that is warmer than any to date (low emissions scenario) and future temperatures could be as much as 10° F (5.6° C) warmer (high emissions scenario). New Jersey can also expect that by the middle of the 21st century, 70 percent of summers will be hotter than the warmest summer experienced to date (Runkle, New Jersey State Climate Summary 2017). The increase in temperatures is expected to be felt more during the winter months (December, January, and February), resulting in less intense cold waves, fewer sub-freezing days, and less snow accumulation.

As temperatures increase, Earth's atmosphere can hold more water vapor which leads to a greater potential for precipitation. Currently, New Jersey receives an average of 46 inches of precipitation each year (Office of the New Jersey State Climatologist 2020). Since the end of the twentieth century, New Jersey has experienced slight increases in the amount of precipitation it receives each year, and over the last 10 years there has been a 7.9 percent increase. By 2050, annual precipitation in New Jersey could increase by 4 percent to 11 percent (Horton et al. 2015). By the end of this century, heavy precipitation events are projected to occur two to five times more (Walsh 2014) and with more intensity (Huang 2017) than in the last century. New Jersey will experience more intense rain events, less snow, and more rainfalls (Fan 2014). Also, small decreases in the amount of precipitation may occur in the summer months, resulting in greater potential for more frequent and prolonged droughts (Trenberth 2011).

A warmer atmosphere means storms have the potential to be more intense (Guilbert 2015) and occur more often (Broccoli 2020). In New Jersey, extreme storms typically include coastal nor'easters, snowstorms, spring and summer thunderstorms, tropical storms, and on rare occasions hurricanes. Most of these events occur in the warmer months between April and October, with nor'easters occurring between September and April. Over the last 50 years, in New Jersey, storms that resulted in extreme rain increased by 71 percent (Walsh 2014) which is a faster rate than anywhere else in the United States (Huang et al. 2017).

4.3.8.2 Vulnerability Assessment

To evaluate the geological hazard in Gloucester County, slopes above 15-percent were selected using the 2015 USGS 1-Meter Digital Elevation Model (DEM). Additionally, the USGS carbonate rock layer was used to identify the geologic hazard area. The following text summarizes the potential impact of geological hazards on the County. Refer to Section 4.2 (Methodology and Tools) for additional details on the methodology used to assess geological hazard risk.

Impact on Life, Health, and Safety

Generally, a landslide, subsidence or sink hole event is an isolated incidence and impacts the populations within the immediate area. Specifically, the population located downslope of the landslide hazard areas are particularly vulnerable. In addition to causing damages to residential buildings and displacing residents, geologic hazard events can block off or damage major roadways and inhibit travel for emergency responders or populations trying to evacuate the area.

Table 4.3.8-1 summarizes the population living on landscapes with carbonate bedrock susceptible to subsidence or sink hole events and on landscapes with slopes greater than or equal to 15-percent susceptible to landslide events. Overall, 32,985 persons and 6,619 persons are living on carbonate bedrock or landscapes with slopes greater than or equal to 15-percent, respectively. The Borough of Wenonah and the Township of Woolwich have the greatest proportion of their populations exposed to the carbonate bedrock geologic hazard area or landslide susceptible areas with landscape slopes greater than or equal to 15-percent, respectively.

Table 4.3.8-1. Estimated Population Living in the Geologic Hazard Areas

Jurisdiction	Total Population (American Community Survey 2015-2019)	Estimated Population Located in the Geologic Hazard Areas			
		Number of Persons Located in the Carbonate Rock Hazard Area	Percent of Total	Number of Persons Located in the Steep Slopes (Greater Than 15% Grade) Hazard Area	Percent of Total
Clayton (B)	8,626	0	0.0%	48	0.6%
Deptford (Twp)	30,448	12,475	41.0%	743	2.4%
East Greenwich (Twp)	10,488	3,108	29.6%	383	3.7%
Elk (Twp)	4,135	0	0.0%	108	2.6%
Franklin (Twp)	16,440	0	0.0%	64	0.4%
Glassboro (B)	19,826	0	0.0%	282	1.4%
Greenwich (Twp)	4,831	0	0.0%	28	0.6%
Harrison (Twp)	12,995	3,133	24.1%	754	5.8%
Logan (Twp)	5,924	0	0.0%	25	0.4%
Mantua (Twp)	14,941	4,810	32.2%	704	4.7%
Monroe (Twp)	36,789	0	0.0%	94	0.3%
National Park (B)	2,959	0	0.0%	19	0.6%
Newfield (B)	1,521	0	0.0%	10	0.6%
Paulsboro (B)	5,904	0	0.0%	10	0.2%
Pitman (B)	8,805	0	0.0%	126	1.4%
South Harrison (Twp)	3,148	57	1.8%	201	6.4%
Swedesboro (B)	2,579	619	24.0%	88	3.4%
Washington (Twp)	47,833	64	0.1%	1,233	2.6%
Wenonah (B)	2,259	2,218	98.2%	92	4.1%
West Deptford (Twp)	21,149	1,378	6.5%	254	1.2%
Westville (B)	4,169	0	0.0%	73	1.7%
Woodbury (C)	9,861	0	0.0%	97	1.0%
Woodbury Heights (B)	2,986	598	20.0%	150	5.0%

TETRA TECH

Jurisdiction	Total Population (American Community Survey 2015-2019)	Estimated Population Located in the Geologic Hazard Areas			
		Number of Persons Located in the Carbonate Rock Hazard Area	Percent of Total	Number of Persons Located in the Steep Slopes (Greater Than 15% Grade) Hazard Area	Percent of Total
Woolwich (Twp)	12,549	4,524	36.1%	1,033	8.2%
Gloucester County (Total)	**291,165**	**32,985**	**11.3%**	**6,619**	**2.3%**

Source: American Community Survey (ACS) 2015 – 2019; USGS 2015/n.d.
Notes: B = Borough, C = City, Twp = Township; % = Percent

Research has also shown that some populations, while they may not have more hazard exposure, may experience exacerbated impacts and prolonged recovery if/when impacted. For example, persons over the age of 65 and people below the poverty level are most vulnerable to geologic hazards because of the potential limited access to mobilization or medical resources if a landslide, subsidence or sink hole event occurs. According to the 2019 ACS 5-Year Population Estimate, there are 44,794 persons over 65 years old and 21,340 persons living below the poverty level out of the total 291,165 persons that live in Gloucester County. For the two municipalities with the greatest proportion of its population in the geologic hazard areas; over 14-percent and 1.8-percent of the Borough of Wenonah's population is over the age of 65 or living under the poverty level, respectively; and over 10-percent and 3.2-percent of the Township of Woolwich's population is over the age of 65 or living under the poverty level, respectively.

Impact on General Building Stock

In general, the built environment is vulnerable to the geologic hazard if built on soil/geology susceptible to landsliding or sink holes such as carbonate bedrock or slopes that are greater than 15-percent. Geologic hazard areas may destabilize the foundation of structures resulting in monetary losses to businesses and residents. There are 12,425 buildings with a replacement cost value of approximately $9.9 billion built on lands with carbonate bedrock. Furthermore, there are 2,426 buildings with a replacement cost value of approximately $1.9 billion built on lands with slopes greater than 15-percent.

The Township of Deptford has the greatest number of buildings built on carbonate bedrock; 4,615 buildings (40.9-percent of its total building stock) with an estimated replacement cost of $3.8 billion. The Township of Washington has the greatest number of buildings built on landscapes with slopes greater than 15-percent; 433 buildings (2.5-percent of its total building stock) with an estimated replacement cost of $274.2 million. Table 4.3.8-2 and Table 4.3.8-3 summarize the number of buildings built on each geologic hazard area and the total replacement cost of these buildings by municipality.

Table 4.3.8-2. Number and Value of Buildings Built on Lands with Carbonate Bedrock by Municipality

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Estimated Building Stock Located in the Carbonate Rock Geologic Hazard Area			
			Number of Buildings Located in the Carbonate Rock Hazard Area	Percent of Total	Total Replacement Cost Value of Buildings Located in the Carbonate Rock Hazard Area	Percent of Total
Clayton (B)	3,295	$1,933,299,905	0	0.0%	$0	0.0%
Deptford (Twp)	11,284	$10,081,159,584	4,615	40.9%	$3,805,674,797	37.8%
East Greenwich (Twp)	4,346	$2,927,045,409	1,243	28.6%	$736,619,735	25.2%
Elk (Twp)	2,339	$1,784,179,937	0	0.0%	$0	0.0%
Franklin (Twp)	8,432	$5,637,186,975	0	0.0%	$0	0.0%
Glassboro (B)	5,959	$5,816,332,907	0	0.0%	$0	0.0%
Greenwich (Twp)	2,807	$2,734,741,222	0	0.0%	$0	0.0%
Harrison (Twp)	4,817	$4,828,239,008	1,153	23.9%	$1,093,375,153	22.6%
Logan (Twp)	2,805	$6,591,573,691	0	0.0%	$0	0.0%
Mantua (Twp)	6,569	$4,738,271,524	2,042	31.1%	$1,239,253,342	26.2%
Monroe (Twp)	12,553	$8,458,118,166	0	0.0%	$0	0.0%
National Park (B)	1,483	$781,021,288	0	0.0%	$0	0.0%
Newfield (B)	891	$622,948,021	0	0.0%	$0	0.0%
Paulsboro (B)	2,615	$2,076,864,026	0	0.0%	$0	0.0%
Pitman (B)	3,521	$2,916,470,733	0	0.0%	$0	0.0%
South Harrison (Twp)	1,726	$1,494,748,661	70	4.1%	$72,820,627	4.9%
Swedesboro (B)	1,040	$936,236,069	240	23.1%	$204,969,585	21.9%
Washington (Twp)	17,413	$13,732,374,547	22	0.1%	$19,641,405	0.1%
Wenonah (B)	930	$778,702,966	914	98.3%	$753,782,490	96.8%
West Deptford (Twp)	7,561	$9,201,121,261	441	5.8%	$428,348,234	4.7%
Westville (B)	1,733	$1,529,846,612	0	0.0%	$0	0.0%
Woodbury (C)	3,605	$4,139,381,075	0	0.0%	$0	0.0%
Woodbury Heights (B)	1,295	$1,265,332,236	237	18.3%	$161,834,280	12.8%
Woolwich (Twp)	4,074	$4,551,585,778	1,448	35.5%	$1,410,692,807	31.0%
Gloucester County (Total)	**113,093**	**$99,556,781,602**	**12,425**	**11.0%**	**$9,927,012,456**	**10.0%**

Source: Gloucester County GIS 2021; MODIV 2020; RS Means 2021; USGS n.d.
Notes: B = Borough, C = City, Twp = Township, % = Percent

Table 4.3.8-3. Number and Value of Buildings Built on Landscapes with Slopes Greater than 15-Percent by Municipality

Jurisdiction	Total Number of Buildings	Total Replacement Cost Value (RCV)	Estimated Building Stock Located in the Landslide Geologic Hazard Area			
			Number of Buildings Located in the Steep Slope (Greater Than 15% Grade) Hazard Area	Percent of Total	Total Replacement Cost Value of Buildings Located in the Steep Slope (Greater Than 15% Grade) Hazard Area	Percent of Total
Clayton (B)	3,295	$1,933,299,905	18	0.5%	$6,952,231	0.4%
Deptford (Twp)	11,284	$10,081,159,584	268	2.4%	$207,433,441	2.1%
East Greenwich (Twp)	4,346	$2,927,045,409	148	3.4%	$86,574,864	3.0%
Elk (Twp)	2,339	$1,784,179,937	54	2.3%	$35,798,900	2.0%
Franklin (Twp)	8,432	$5,637,186,975	30	0.4%	$16,684,152	0.3%
Glassboro (B)	5,959	$5,816,332,907	81	1.4%	$56,793,862	1.0%
Greenwich (Twp)	2,807	$2,734,741,222	14	0.5%	$7,170,006	0.3%
Harrison (Twp)	4,817	$4,828,239,008	267	5.5%	$246,179,014	5.1%
Logan (Twp)	2,805	$6,591,573,691	14	0.5%	$18,062,493	0.3%
Mantua (Twp)	6,569	$4,738,271,524	305	4.6%	$220,335,692	4.7%
Monroe (Twp)	12,553	$8,458,118,166	34	0.3%	$24,899,411	0.3%
National Park (B)	1,483	$781,021,288	9	0.6%	$3,514,904	0.5%
Newfield (B)	891	$622,948,021	5	0.6%	$3,963,968	0.6%
Paulsboro (B)	2,615	$2,076,864,026	5	0.2%	$5,103,090	0.2%
Pitman (B)	3,521	$2,916,470,733	54	1.5%	$44,237,536	1.5%
South Harrison (Twp)	1,726	$1,494,748,661	93	5.4%	$92,258,414	6.2%
Swedesboro (B)	1,040	$936,236,069	36	3.5%	$46,119,682	4.9%
Washington (Twp)	17,413	$13,732,374,547	433	2.5%	$274,219,782	2.0%
Wenonah (B)	930	$778,702,966	38	4.1%	$30,993,054	4.0%
West Deptford (Twp)	7,561	$9,201,121,261	85	1.1%	$62,751,059	0.7%
Westville (B)	1,733	$1,529,846,612	29	1.7%	$23,628,586	1.5%
Woodbury (C)	3,605	$4,139,381,075	37	1.0%	$70,152,135	1.7%
Woodbury Heights (B)	1,295	$1,265,332,236	60	4.6%	$32,153,071	2.5%
Woolwich (Twp)	4,074	$4,551,585,778	309	7.6%	$331,283,693	7.3%
Gloucester County (Total)	**113,093**	**$99,556,781,602**	**2,426**	**2.1%**	**$1,947,263,039**	**2.0%**

Source: Gloucester County GIS 2021; MODIV 2020; RS Means 2021; USGS 2015
Notes: B = Borough, C = City, Twp = Township, % = Percent

Impact on Critical Facilities and Lifelines

To estimate potential risk, the critical facility and lifeline inventory was overlaid upon the geologic hazard areas. There are 46 critical facilities built on lands with carbonate bedrock and 26 critical facilities built on landscapes with slopes greater than 15-percent grade. Of the critical facilities exposed to the carbonate bedrock and steep slope hazard areas 43 and 26 are considered lifelines for the County, respectively. Refer to Table 4.3.8-4 and Table 4.3.8-5 which summarize the number of critical facilities and lifelines exposed to the geologic hazard areas by municipality. Additionally, refer to Appendix E for more information about the distribution of critical facilities exposed to the geologic hazard area by type. Overall, education facilities and wastewater metering stations are the most common critical facilities exposed to geologic hazards caused by carbonate rock landscapes and primary education facilities are the most common critical facility type built on steep slopes with greater than 15-percent grade. The critical facilities exposed to the geologic hazard areas are also categorized by the FEMA lifeline categories, refer to Table 4.3.8-6. Out of the FEMA lifelines in the County, critical facilities that provide safety and security to the County are most at risk to impacts from the geologic hazard areas.

Table 4.3.8-4. Number of Critical Facilities and Lifelines Built on the Carbonate Bedrock Geologic Hazard Area

Jurisdiction	Total Critical Facilities Located in Jurisdiction	Total Lifelines Located in Jurisdiction	Number of Critical Facilities and Lifeline Facilities Located in the Carbonate Rock Geologic Hazard Area			
			Critical Facilities	Percent of Total Critical Facilities	Lifelines	Percent of Total Lifelines
Clayton (B)	25	25	0	0.0%	0	0.0%
Deptford (Twp)	79	77	18	22.8%	17	22.1%
East Greenwich (Twp)	46	46	3	6.5%	3	6.5%
Elk (Twp)	6	6	0	0.0%	0	0.0%
Franklin (Twp)	35	35	0	0.0%	0	0.0%
Glassboro (B)	137	137	0	0.0%	0	0.0%
Greenwich (Twp)	31	31	0	0.0%	0	0.0%
Harrison (Twp)	26	26	1	3.8%	1	3.8%
Logan (Twp)	50	50	0	0.0%	0	0.0%
Mantua (Twp)	30	30	5	16.7%	5	16.7%
Monroe (Twp)	29	26	0	0.0%	0	0.0%
National Park (B)	41	41	0	0.0%	0	0.0%
Newfield (B)	9	9	0	0.0%	0	0.0%
Paulsboro (B)	29	29	0	0.0%	0	0.0%
Pitman (B)	19	19	0	0.0%	0	0.0%
South Harrison (Twp)	12	12	0	0.0%	0	0.0%
Swedesboro (B)	9	9	3	33.3%	3	33.3%
Washington (Twp)	75	75	0	0.0%	0	0.0%
Wenonah (B)	4	4	4	100.0%	4	100.0%
West Deptford (Twp)	157	149	4	2.5%	2	1.3%
Westville (B)	23	21	0	0.0%	0	0.0%
Woodbury (C)	59	59	0	0.0%	0	0.0%
Woodbury Heights (B)	9	9	0	0.0%	0	0.0%
Woolwich (Twp)	16	16	8	50.0%	8	50.0%
Gloucester County (Total)	**956**	**941**	**46**	**4.8%**	**43**	**4.6%**

Source: Gloucester County Planning Partnership 2021; Gloucester County GIS 2021; FEMA 2020; USGS 2015/n.d.
Notes: B = Borough, C = City, T = Township, % = Percent

Table 4.3.8-5. Number of Critical Facilities and Lifelines Built on the Steep Slope (Greater Than 15-Percent Grade) Geologic Hazard Area

Jurisdiction	Total Critical Facilities Located in Jurisdiction	Total Lifelines Located in Jurisdiction	Number of Critical Facilities and Lifeline Facilities Located in the Steep Slope (Greater Than 15% Grade) Geologic Hazard Area			
			Critical Facilities	Percent of Total Critical Facilities	Lifelines	Percent of Total Lifelines
Clayton (B)	25	25	1	4.0%	1	4.0%
Deptford (Twp)	79	77	4	5.1%	4	5.2%
East Greenwich (Twp)	46	46	0	0.0%	0	0.0%
Elk (Twp)	6	6	0	0.0%	0	0.0%
Franklin (Twp)	35	35	1	2.9%	1	2.9%
Glassboro (B)	137	137	2	1.5%	2	1.5%
Greenwich (Twp)	31	31	2	6.5%	2	6.5%
Harrison (Twp)	26	26	0	0.0%	0	0.0%
Logan (Twp)	50	50	1	2.0%	1	2.0%
Mantua (Twp)	30	30	2	6.7%	2	6.7%
Monroe (Twp)	29	26	1	3.4%	1	3.8%
National Park (B)	41	41	1	2.4%	1	2.4%
Newfield (B)	9	9	0	0.0%	0	0.0%
Paulsboro (B)	29	29	2	6.9%	2	6.9%
Pitman (B)	19	19	0	0.0%	0	0.0%
South Harrison (Twp)	12	12	0	0.0%	0	0.0%
Swedesboro (B)	9	9	0	0.0%	0	0.0%
Washington (Twp)	75	75	0	0.0%	0	0.0%
Wenonah (B)	4	4	1	25.0%	1	25.0%
West Deptford (Twp)	157	149	4	2.5%	4	2.7%
Westville (B)	23	21	0	0.0%	0	0.0%
Woodbury (C)	59	59	2	3.4%	2	3.4%
Woodbury Heights (B)	9	9	2	22.2%	2	22.2%
Woolwich (Twp)	16	16	0	0.0%	0	0.0%
Gloucester County (Total)	**956**	**941**	**26**	**2.7%**	**26**	**2.8%**

Source: Gloucester County Planning Partnership 2021; Gloucester County GIS 2021; FEMA 2020; USGS 2015/n.d.
Notes: B = Borough, C = City, T = Township, % = Percent

Table 4.3.8-6. Number of Lifelines Categorized by FEMA Lifeline Categories Exposed to the Geologic Hazard Areas

FEMA Lifeline Category	Number of Lifelines	Number of Lifelines Located in the Carbonate Rock Hazard Area	Number of Lifelines Located in the Steep Slope (Greater Than 15% Grade) Hazard Area
Energy	5	0	0
Food, Water, Shelter	214	15	6
Hazardous Materials	116	5	2
Health and Medical	102	6	0
Safety and Security	481	17	14
Transportation	23	0	4
Gloucester County (Total)	**956**	**43**	**26**

Source: Gloucester County Planning Partnership 2021; Gloucester County GIS 2021; FEMA 2020; USGS 2015/n.d.

In addition to critical facilities, a significant amount of infrastructure can be exposed to mass movements of geological material:

- *Roads*—Access to major roads is crucial to life-safety after a disaster event and to response and recovery operations. Landslides can block egress and ingress on roads, causing isolation for neighborhoods, traffic problems, and delays for public and private transportation. This can result in economic losses for businesses.
- *Bridges*—Landslides can significantly impact road bridges. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use.
- *Power Lines*—Power lines are generally elevated above steep slopes; but the towers supporting them can be subject to landslides. A landslide could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Power and communication failures due to landslides can create problems for vulnerable populations and businesses.
- *Rail Lines*—Similar to roads, rail lines are important for response and recovery operations after a disaster. Landslides can block travel along the rail lines, which would become especially troublesome, because it would not be as easy to detour a rail line as it is on a local road or highway. Many residents rely on public transport to get to work around the County and a landslide event could prevent travel to and from work.

The number of miles major transportation routes are exposed to the geologic hazard areas of concern was assessed and is summarized in Table 4.3.8-7. Out of the 2,040 miles of transportation routes in the County, 235 miles are built on lands with carbonate bedrock. Local roads have the most miles at risk to the geologic hazard area, but the New Jersey Turnpike has the greatest proportion of its miles within the County at risk to the carbonate rock hazard area.

Table 4.3.8-7. Transportation Routes Located in the Carbonate Rock Geologic Hazard Area

Road Type	Total Miles for County	Roadway Miles Exposed to the Geologic Hazard Areas	
		Miles Exposed to the Carbonate Rock Hazard Area	Percent of Total
County Routes	405	44	10.9%
Interstate	55	0	0.0%
Local Roads	1,329	155	11.7%
State Highway	139	12	8.4%
Turnpike	39	20	51.1%
US Highway	73	4	5.8%
Gloucester County (Total)	**2,040**	**235**	**11.5%**

Source: USGS n.d., NJOIT 2017
Notes: % = Percent

Several other types of infrastructure may also be exposed to the geologic hazards, including water and sewer infrastructure. At this time, all critical facilities, infrastructure, and transportation corridors located within the hazard areas are considered vulnerable until more information becomes available.

Impact on the Economy

Geologic hazards can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property, and infrastructure due to ground failure, which also threatens transportation corridors, fuel and energy conduits, and communication lines (USGS 2020). Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity may also occur, but are difficult to measure.

Buildings susceptible to landslide events were summarized earlier in this section. Losses to these structures will impact the local tax base and economy.

Impact on the Environment

A landslide or sinkhole/subsidence event will alter the landscape. In addition to changes in topography, vegetation and wildlife habitats may be damaged or destroyed, forest productivity can decline, or massive wasting and erosion of natural surfaces may occur causing soil and sediment runoff (USGS 2020). Soil and sediment runoff can accumulate downslope potentially blocking waterways and roadways and impacting quality of streams and other water bodies. Habitats stripped of fertile soils can delay the growth of new vegetation post-landslide event.

Steep slopes within the Pinelands Region play an important ecological, recreational, scenic, and functional role. They provide specialized habitats for rare plant and animal species. Areas of steep slope provide recreational opportunities and contribute to the rural character of the Pinelands Region (NJ Pinelands Commission 2021).

Future Changes That May Impact Vulnerability

Understanding future changes that effect vulnerability in the County can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The County considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change

Projected Development

As discussed and illustrated in Section 3 (County Profile), areas targeted for future growth and development have been identified across the County. The New Jersey Highlands Council has identified areas of potential growth (Sewer Service Areas) that may provide insight as to where potential new development may occur in Gloucester County. Further, the New Jersey Pinelands Commission has identified Pinelands Management Area Boundaries, including regional growth areas and rural development areas that may also provide insight to where development and growth may occur in the County. In addition, each community was requested to provide recent and anticipated new development and infrastructure projects; summarized in Section 9 (Jurisdictional Annexes). According to the Gloucester County Planning Partnership, there are 38 recent or anticipated new development sites in Gloucester County. Of these new development sites, nine are located in the geologic hazard areas.

Gloucester County's municipalities have their own steep slope ordinances in place to regulate the intensity and use in areas of steep slope terrain in order to limit soil loss, erosion, excessive stormwater runoff, excessive removal of vegetation, the degradation of surface water and to maintain the natural topography of land and continuing replenishment of groundwater resources [(South Harrison n.d.), (Harrison n.d.)]. Refer to Figure 4.3.8-3 and Figure 4.3.8-4 which shows the distribution of new development projects and their proximity to the geologic hazard areas.

Projected Changes in Population

Gloucester County has experienced an increase in its population since 2010. According to the U.S. Census Bureau, the County's population increased by approximately 1-percent between 2010 and 2019 (U.S. Census Bureau 2020). Changes in population and density not only create issues for local residents during evacuation of a landslide or ground failure event but can also have an effect on commuters that travel into and out of the County for work, particularly during a geologic event that breaches major transportation corridors, which are also major commuter roads. Refer to Section 3 (County Profile) for more information about population trends in the County.

Climate Change

A direct impact of climate change on landslides is difficult to determine. Multiple secondary effects of climate change have the potential to increase the likelihood of landslides. Warming temperatures resulting in wildfires would reduce vegetative cover along steep slopes and destabilize the soils due to destruction of the root system; increased intensity of rainfall events would increase saturation of soils on steep slopes. Under these future conditions, the County's assets located on or at the base of these steep slopes will have an increased risk to landslides. Roadways and other transportation infrastructure located in these areas will also be at an increased risk of closure, which would impact the County's risk as described above.

Higher temperatures and the possibility of more intense, less frequent summer rainfall may lead to changes in water resource availability. Increase in average temperatures may lead to an increase in the frequency of droughts. Sinkhole activity intensifies in some karst areas during periods of drought. With an increase in drought periods, the number of sinkholes could increase. Additionally, changes to the water balance of an area including over-withdrawal of groundwater, diverting surface water from a large area and concentrating it in a single point, artificially creating ponds of surface water, and drilling new water wells will cause sinkholes. These actions can also serve to accelerate the natural processes of bedrock degradation, which can have a direct impact on sinkhole creation.

Vulnerability Changes Since the 2016 HMP

This updated HMP developed and utilized an updated building stock and critical facility/lifeline inventories to assess the County's risk to the geologic hazard. The building inventory was updated using RS Means 2021 values, which is more current and reflects replacement cost versus the building stock improvement values reported in the 2016 HMP. Further, the 2019 5-year population estimates from the ACS were used to evaluate the population exposed. Additionally, a carbonate rock layer from USGS and the 2015 1-meter Digital Elevation Model (DEM) from USGS were referenced to assess the County's assets to the geologic hazard.

Overall, changes in population, development and climate did not change the County's vulnerability to the geologic hazard. The County remains vulnerable to the geologic hazard.

Figure 4.3.8-3. Recent and Anticipated New Development and Areas of Steep Slopes (Greater than 15-Percent Slope)

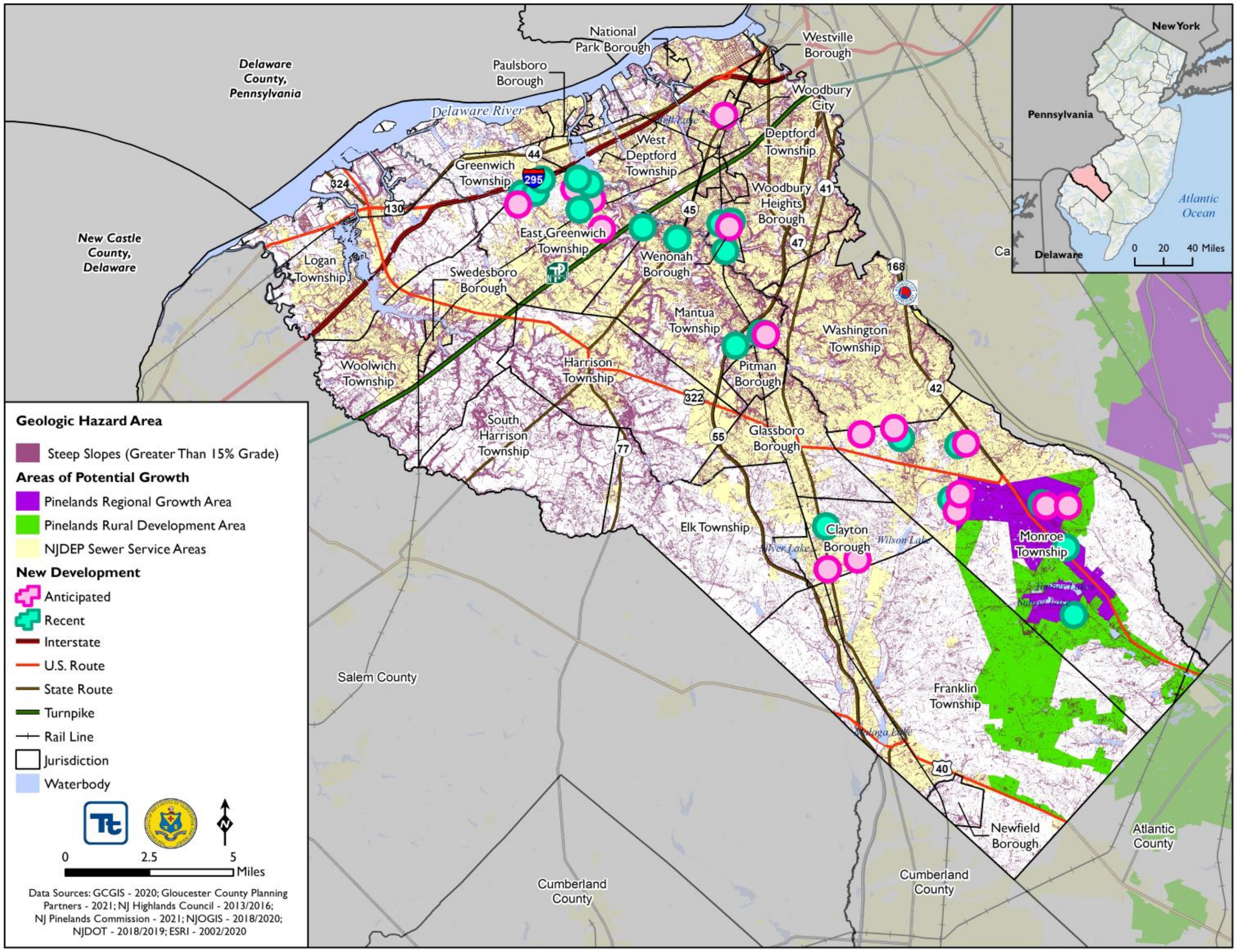


Figure 4.3.8-4. Recent and Anticipated New Development and Carbonate Rock Formations in Gloucester County